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Sex Differences in the Brain

by Doreen Kimura

DIVERGING PLAY STYLES of boys and girls—boys' preference for mock fighting over playing house—may be dictated by hormonal differences.



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Men and women display patterns of behavioral and cognitive differences that reflect varying hormonal influences on brain development

Men and women differ not only in their physical attributes and reproductive function but also in many other characteristics, including the way they solve intellectual problems. For the past few decades, it has been ideologically fashionable to insist that these behavioral differences are minimal and are the consequence of variations in experience during development before and after adolescence. Evidence accumulated more recently, however, suggests that the effects of sex hormones on brain organization occur so early in life that from the start the environment is acting on differently wired brains in boys and girls. Such effects make evaluating the role of experience, independent of physiological predisposition, a difficult if not dubious task. The biological bases of sex differences in brain and behavior have become much better known through increasing numbers of behavioral, neurological and endocrinological studies.

We know, for instance, from observations of both humans and nonhumans that males are more aggressive than females, that young males engage in more rough-and-tumble play than females and that females are more nurturing. We also know that in general males are better at a variety of spatial or navigational tasks. How do these and other sex differences come about? Much of our information and many of our ideas about how sexual differentiation takes place derive from research on animals. From such investigations, it appears that perhaps the most important factor in the differentiation of males and females is the level of exposure to various sex hormones early in life.

In most mammals, including humans, the developing organism has the potential to be male or female. Producing a male, however, is a complex process. When a Y chromosome is present, testes, or male gonads, form. This development is the critical first step toward becoming a male. When no Y chromosome is present, ovaries form [see "The Key to Masculinity," on page 20].

Testes produce male hormones, or androgens (testosterone chief among them), which are responsible not only for transformation of the genitals into male organs but also for organization of corresponding male behaviors early in life. As with genital formation, the intrinsic tendency that occurs in the absence of masculinizing hormonal influence, according to seminal studies by Robert W. Goy of the University of Wisconsin, is to develop female genital structures and behavior. Female anatomy and probably most behavior associated with females are thus the default modes in the absence of androgens.

If a rodent with functional male genitals is deprived of androgens immediately after birth (either by castration or by the administration of a compound that blocks androgens), male sexual behavior, such as mounting, will be reduced, and more female sexual behavior, such as lordosis (arching of the back when receptive to coitus), will be expressed. Similarly, if androgens are administered to a female directly after birth, she will display more male sexual behavior and less female behavior in adulthood. These lifelong effects of early exposure to sex hormones are characterized as "organizational" because they appear to alter brain function permanently during a critical period in prenatal or early postnatal development. Administering the same sex hormones at later stages or in the adult has no such effect.

Not all the behaviors that categorize males are organized at the same time, however. Organization by androgens of

the male-typical behaviors of mounting and of rough-and-tumble play, for example, occur at different times prenatally in rhesus monkeys.

The area in the brain that regulates female and male reproductive behavior is the hypothalamus. This tiny structure at the base of the brain connects to the pituitary, the master endocrine gland. It has been shown that a region of the hypothalamus is visibly larger in male rats than in females and that this size difference is under hormonal control. Scientists have also found parallel sex differences in a clump of nerve cells in the human brain—parts of the interstitial nucleus of the anterior hypothalamus—that is larger in men than in women. Even sexual orientation and gender identity have been related to anatomical variation in the hypothalamus. In 1991, while at the Salk Institute for Biological Studies in San Diego, Simon Levay reported that one of the interstitial nuclei of the anterior hypothalamus that is usually larger in human males than in females is smaller in homosexual than in heterosexual men. Other researchers, Jiang-Ning Zhou of the Netherlands Institute of Brain Research and his colleagues there and at Free University in Amsterdam, observed another part of the hypothalamus to be smaller in male-to-female transsexuals than in a male control group. These findings are consistent with suggestions that sexual orientation and gender identity have a significant biological component.

Hormones and Intellect

What of differences in intellectual function between men and women? Major sex differences in function seem to lie in patterns of ability rather than in overall level of intelligence (measured as IQ), although some researchers, such as Richard Lynn of the University of Ulster in Northern Ireland, have argued that there exists a small IQ difference favoring human males. Differences in intellectual pattern refer to the fact that people have different intellectual strengths. For example, some people are especially good at using words, whereas others are better at dealing with external stimuli, such as identifying an object in a different orientation. Individuals may have the same overall intelligence but differing abilities.

Sex differences in problem solving have been systematically studied in adults in laboratory situations. On average, men perform better than women at certain spatial tasks. In particular, men seem to have an advantage in tests that require the subject to imagine rotating an object or manipulating it in some other way. They also outperform women in mathematical reasoning tests and in navigating their way through a route. Further, men exhibit more accuracy in tests of target-directed motor skills—that is, in guiding or intercepting projectiles.

Women, on average, excel on tests that measure recall of words and on tests that challenge the person to find words that begin with a specific letter or fulfill some other constraint. They also tend to be better than men at rapidly identifying matching items and performing certain precision manual tasks, such as placing pegs in designated holes on a board.

In examining the nature of sex differences in navigating routes, one study found that men completed a computer simulation of a maze or labyrinth task more quickly and with fewer errors than women did. Another study by different researchers used a path on a tabletop map to measure route learning. Their

results showed that although men learned the route in fewer trials and with fewer errors, women remembered more of the landmarks, such as pictures of different types of buildings, than men did. These results and others suggest that women tend to use landmarks as a

strategy to orient themselves in everyday life more than men do.

Other findings seemed also to point to female superiority in landmark memory. Researchers tested the ability of individuals to recall objects and their locations within a confined space—

such as in a room or on a tabletop. In these studies, women were better able to remember whether items had changed places or not. Other investigators found that women were superior at a memory task where they had to remember the locations of pictures on cards that were turned over in pairs. At this kind of object location, in contrast to other spatial tasks, women appeared to have the advantage.

It is important to keep in mind that some of the average sex differences in cognition vary from slight to quite large and that men and women overlap enormously on many cognitive tests that show average differences. For example, whereas women perform better than men in both verbal memory (recalling words from lists or paragraphs) and verbal fluency (finding words that begin with a specific letter), there was a large difference in memory ability but only a small disparity for the fluency tasks. On the whole, variation between men and women tends to be smaller than deviations within each sex, but very large differences between the groups do exist—in men's high level of visual-spatial targeting ability, for one.

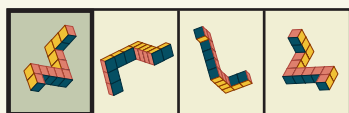
Although it used to be thought that sex differences in problem solving did not appear until puberty, the accumulated evidence now suggests that some cognitive and skill differences are present much earlier. For example, researchers have found that three- and four-year-old boys were better at targeting and mentally rotating figures within a clock face than girls of the same age were. Prepubescent girls, however, excelled at recalling lists of words.

Male and female rodents have also been found to solve problems differently. Christina L. Williams of Duke University has shown that female rats have a greater tendency to use landmarks in spatial learning tasks, as it appears women do. In Williams's experiment, female rats used landmark cues, such as pictures on the wall, in preference to geometric cues: angles and the shape of the room, for instance. If no landmarks were available, however, females used the geometric cues. In contrast, males did not use landmarks at all, preferring geometric cues almost exclusively.

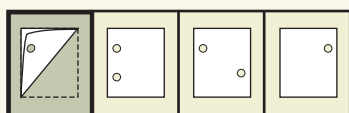
Williams also found that hormonal manipulation during the critical period could alter these behaviors. Depriving newborn males of sex hormones by castrating them or administering hormones to newborn females resulted in

Problem-Solving Tasks Favoring Men

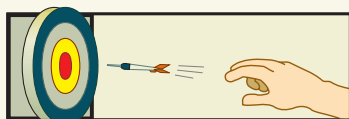
Men tend to perform better than women on certain spatial tasks. They do well on tests that involve mentally rotating an object or manipulating it in some fashion, such as imagining turning this three-dimensional object



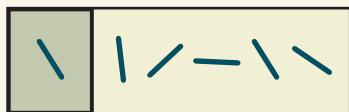
or determining where the holes punched in a folded piece of paper will fall when the paper is unfolded:



Men also are more accurate than women at target-directed motor skills, such as guiding or intercepting projectiles:



They do better at matching lines with identical slopes:



And men tend to do better than women on tests of mathematical reasoning:

1,100	If only 60 percent of seedlings will survive, how many must be planted to obtain 660 trees?
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Problem-Solving Tasks Favoring Women

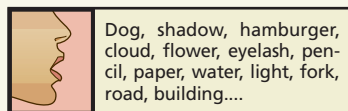
Women tend to perform better than men on tests of perceptual speed in which subjects must rapidly identify matching items—for example, pairing the house on the far left with its twin:



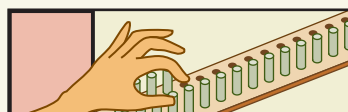
In addition, women remember whether an object, or a series of objects, has been displaced:



When read a story, paragraph or a list of unrelated words, women demonstrate better recall:



Women do better on precision manual tasks—that is, those involving fine-motor coordination—such as placing the pegs in holes on a board:



And women do better than men on mathematical calculation tests:

77	$14 \times 3 - 17 + 52$
43	$2(15 + 3) + 12 - \frac{15}{3}$

DOREEN KIMURA AND JOHN MENGEL

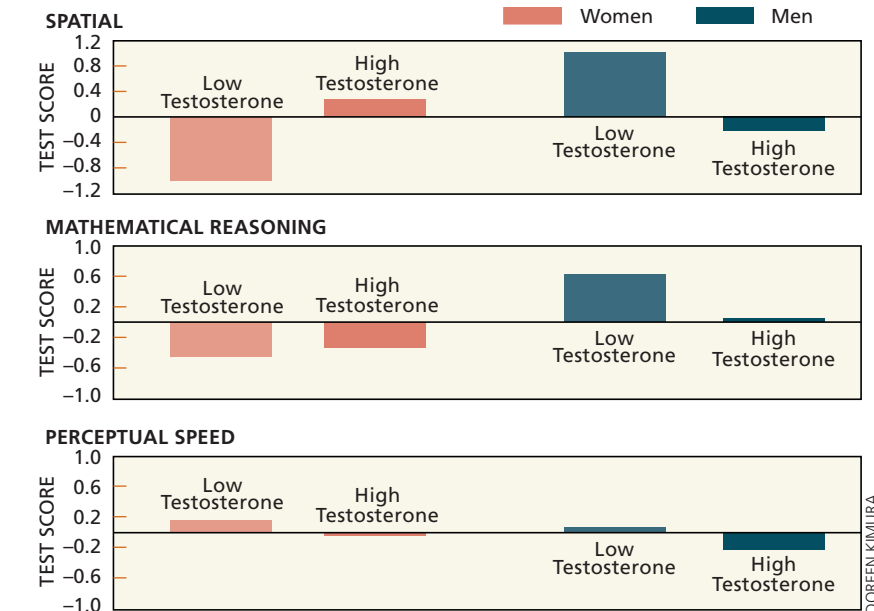
TESTOSTERONE LEVELS can affect performance on some tests [see boxes on opposite page for examples of tests]. Women with high levels of testosterone perform better on spatial tasks (top) than women with low levels do, but men with low levels outperform men with high levels. On a mathematical reasoning test (middle), low testosterone corresponds to better performance in men; in women there is no such relation. On a test of perceptual speed in which women usually excel (bottom), no relation is found between testosterone and performance.

a complete reversal of sex-typed behaviors in the adult animals. Treated males behaved like females and treated females like males.

Structural differences may parallel behavioral ones. Lucia F. Jacobs, then at the University of Pittsburgh, discovered that the hippocampus—a region thought to be involved in spatial learning in both birds and mammals—is larger in several male species of rodents than in females. At present, there are insufficient data on possible sex differences in hippocampal size in human subjects.

One of the most compelling areas of evidence for hormonally influenced sex differences in humans comes from studies of girls exposed to excess androgens in the prenatal or neonatal stage. The production of abnormally large quantities of adrenal androgens can occur because of a genetic defect in a condition called congenital adrenal hyperplasia (CAH). Before the 1970s a similar condition also unexpectedly appeared in the offspring of pregnant women who took various synthetic steroids. Although the consequent masculinization of the genitals can be corrected by surgery and drug therapy can stop the overproduction of androgens, the effects of prenatal exposure on the brain cannot be reversed.

Sheri A. Berenbaum of Southern Illinois University at Carbondale and Melissa Hines of the University of California at Los Angeles observed the play behavior of CAH girls and compared it with that of their male and female siblings. Given a choice of transportation and construction toys, dolls and kitchen supplies, or books and board games, the CAH girls preferred the more typically masculine toys—for example, they played with cars for the same amount of time that boys did. Both the CAH girls and the boys differed from unaf-



DOREEN KIMURA

affected girls in their patterns of choice. Berenbaum also found that CAH girls had greater interest in male-typical activities and careers. Because there is every reason to think parents would be at least as likely to encourage feminine preferences in their CAH daughters as in their unaffected daughters, these findings suggest that these preferences were actually altered in some way by the early hormonal environment.

Other researchers also found that spatial abilities that are typically better in males are enhanced in CAH girls. But the reverse was reported in one study of CAH-affected boys—they performed worse than unaffected boys on the spatial tests males usually excel at.

Such studies suggest that although levels of androgen relate to spatial ability, it is not simply the case that the higher the levels, the better the spatial scores. Rather studies point to some optimal level of androgen (in the low male range) for maximal spatial ability. This finding may also be true with men and mathematical reasoning; low-androgen men tested higher. There was no obvious correlation between hormone levels and women's math scores, however.

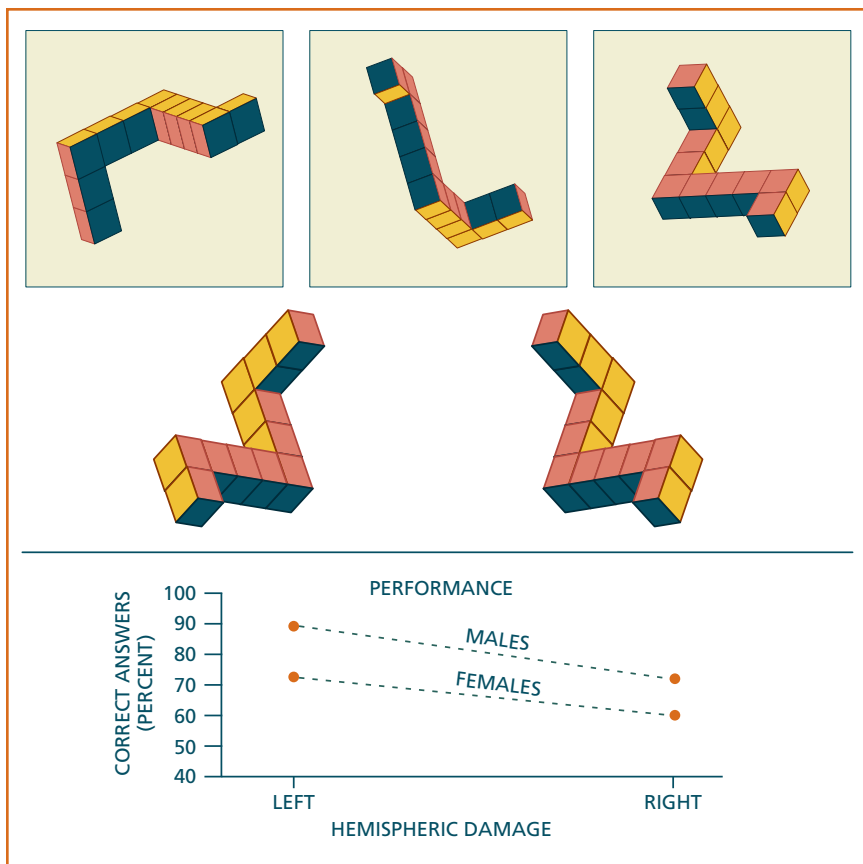
These findings are relevant to the suggestion by Camilla P. Benbow of Iowa State University that high mathematical ability has a significant biological determinant. Benbow and her colleagues have reported consistent sex differences in mathematical reasoning ability that favor males. In mathematically talented youth, the differences were especially sharp at the upper end

of the distribution, where males outnumbered females 13 to one. Benbow argues that these differences are not readily explained by socialization.

It is important to keep in mind that the relation between natural hormone levels and problem solving is based on correlational data. Although some form of connection between the two measures exists, we do not necessarily know how the association is determined nor what its causal basis is. We also know little at present about the relation between adult levels of hormones and those in early life, when abilities appear to become organized in the nervous system.

Hormonal Highs and Lows

One of the most intriguing findings in adults is that cognitive patterns may remain sensitive to hormonal fluctuations throughout life. Elizabeth Hampson of the University of Western Ontario showed that women's performances at certain tasks changed throughout the menstrual cycle as levels of estrogen varied. High levels of the hormone were associated not only with relatively depressed spatial ability but also with enhanced speech and manual skill tasks. In addition, I have observed seasonal fluctuations in spatial ability in men: their performance improves in the spring, when testosterone levels are lower. Whether these hormonally linked fluctuations in intellectual ability represent useful evolutionary adaptations or merely highs and lows of an average test level remains to be seen



DOREEN KIMURA

RIGHT HEMISPHERIC DAMAGE affects spatial ability to the same degree in both sexes (graph at bottom), suggesting that women and men rely equally on that hemisphere for certain spatial tasks. In one test of spatial-rotation performance, photographs of a three-dimensional object must be matched to one of two mirror images of the same object.

through further research endeavors.

A long history of studying people with damage to one half of their brain indicates that in most people the left hemisphere of the brain is critical for speech and the right for certain perceptual and spatial functions. Researchers studying sex differences have widely assumed that the right and left hemispheres of the brain are more asymmetrically organized for speech and spatial functions in men than in women.

This belief rests on several lines of research. Parts of the corpus callosum, a major neural system connecting the two hemispheres, as well as another connector, the anterior commissure, appear to be larger in women, which may permit better communication between hemispheres. Perceptual techniques that measure brain asymmetry in normal-functioning people sometimes show smaller asymmetries in women than in men, and damage to one brain hemisphere sometimes has a lesser effect in women than the compa-

able injury in men does. My own data on patients with damage to one hemisphere of the brain suggest that for functions such as basic speech and spatial ability, there are no major sex differences in hemispheric asymmetry, although there may be such disparities in certain more abstract abilities, such as defining words.

If the known overall differences between men and women in spatial ability were related to differing dependence on the right brain hemisphere for such functions, then damage to that hemisphere might be expected to have a more devastating effect on spatial performance in men. My laboratory has studied the ability of patients with damage to one hemisphere of the brain to visualize the rotation of certain objects. As expected, for both sexes, those with damage to the right hemisphere got lower scores on these tests than those with damage to the left hemisphere did. Also, as anticipated, women did less well than men on this test.

Damage to the right hemisphere, however, had no greater effect on men than on women.

The results of this study and others suggest that the normal differences between men and women on rotational and line orientation tasks need not be the result of different degrees of dependence on the right hemisphere. Some other brain systems may be mediating the higher performance by men.

Another brain difference between the sexes has been shown for speech and certain manual functions. Women incur aphasia (impairment of the power to produce and understand speech) more often after anterior damage than after posterior damage to the brain. In men, posterior damage more often affects speech. A similar pattern is seen in apraxia, difficulty in selecting appropriate hand movements, such as showing how to manipulate a particular object or copying the movements of the experimenter. Women seldom experience apraxia after left posterior damage, whereas men often do.

Men also incur aphasia from left hemisphere damage more often than women do. One explanation suggests that restricted damage within a hemisphere after a stroke more often affects the posterior region of the left hemisphere. Because men rely more on this region for speech than women do, they are more likely to be affected. We do not yet understand the effects on cognitive differences of such divergent patterns of speech and manual functions.

Although my laboratory has not found evidence of sex differences in functional brain asymmetry with regard to basic speech, movement or spatial-rotation abilities, we have found slight differences in some verbal skills. Scores on a vocabulary test and on a verbal fluency test, for instance, were slightly affected by damage to either hemisphere in women, but such scores were affected only by left hemisphere damage in men. These findings suggest that when using some more abstract verbal skills, women do use their hemispheres more equally than men do. But we have not found this to be true for all word-related tasks; for example, verbal memory appears to depend just as much on the left hemisphere in women as in men.

In recent years, new techniques for assessing the brain's activity—including functional magnetic resonance imaging (fMRI) and positron emission

APHASIAS, or speech disorders, occur most often in women when damage is sustained in the anterior of the brain. In men, they occur more frequently when damage is in the posterior region. The data presented at the right derive from one set of patients.

tomography (PET), when used during various problem-solving activities—have shown promise for providing more information about how brain function may vary among normal, healthy individuals. The research using these two techniques has so far yielded interesting, yet at times seemingly conflicting, results.

Some research has shown greater differences in activity between the hemispheres of men than of women during certain language tasks, such as judging if two words rhyme and creating past tenses of verbs. Other research has failed to find sex differences in functional asymmetry. The different results may be attributed in part to different language tasks being used in the various studies, perhaps showing that the sexes may differ in brain organization for some language tasks but not for others.

The varying results may also reflect the complexity of these techniques. The brain is always active to some degree. So for any activity, such as reading aloud, the comparison activity—here, reading silently—is intended to be very similar. We then “subtract” the brain pattern that occurs during silent reading to find the brain pattern present while reading aloud. Yet such methods require dubious assumptions about what the subject is doing during either activity. In addition, the more

complex the activity, the more difficult it is to know what is actually being measured after subtracting the comparison activity.

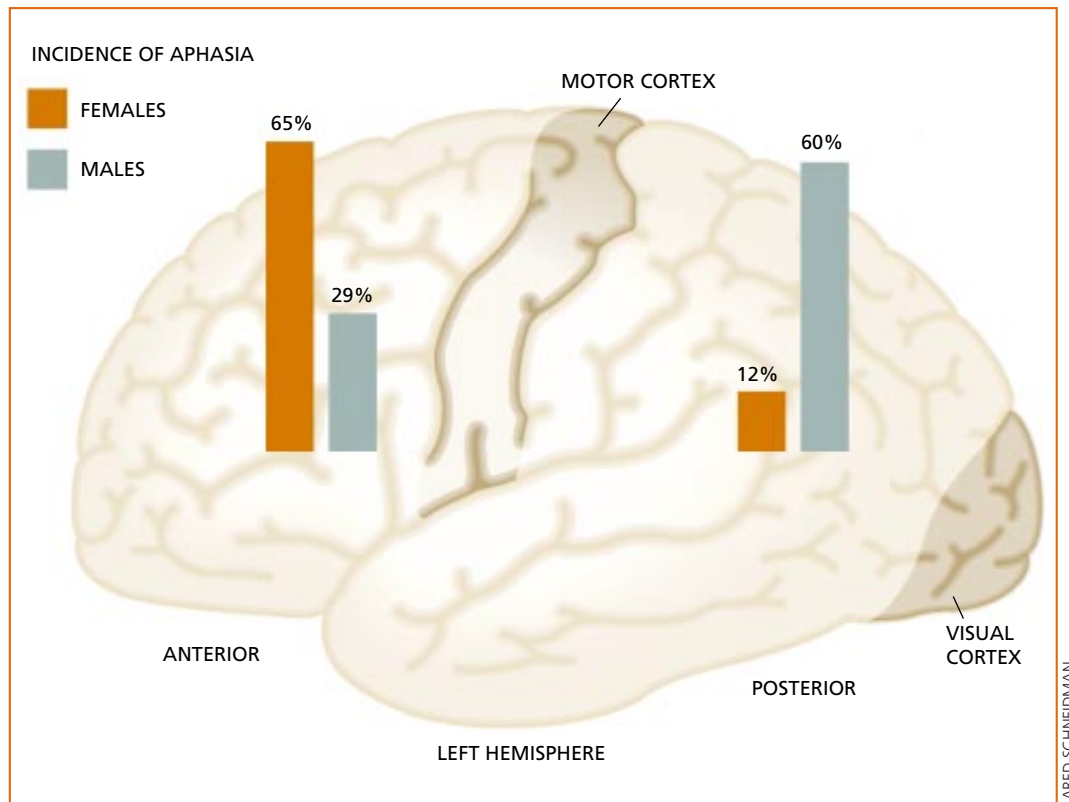
Looking Back

To understand human behavior—how men and women differ from one another, for instance—we must look beyond the demands of modern life. Our brains are essentially like those of our ancestors of 50,000 and more years ago, and we can gain some insight into sex differences by studying the differing roles men and women have played in evolutionary history. Men were responsible for hunting and scavenging, defending the group against predators and enemies, and shaping and using weapons. Women gathered food near the home base, tended the home, prepared food and clothing, and cared for small children. Such specialization

would put different selection pressures on men and women.

Any behavioral differences between individuals or groups must somehow be mediated by the brain. Sex differences have been reported in brain structure and organization, and studies have been done on the role of sex hormones in influencing human behavior. But questions remain regarding how hormones act on human brain systems to produce the sex differences we described, such as in play behavior or in cognitive patterns.

The information we have from laboratory animals helps to guide our explanations, but ultimately these hypotheses must be tested on people. Refinements in brain-imaging techniques, when used in conjunction with our knowledge of hormonal influences and with continuing studies on the behavioral deficits after damage to various brain regions, should provide insight into some of these questions. SA



JARED SCHNEIDMAN

The Author

DOREEN KIMURA studies the neural and hormonal basis of human intellectual functions. She is professor of psychology at Simon Fraser University. Until recently, she was professor of psychology and honorary lecturer in the department of clinical neurological sciences at the University of Western Ontario. Kimura is a fellow of the Royal Society of Canada.

Further Reading

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SEX AND COGNITION. Doreen Kimura. MIT Press, 1999.